Billiards and Brains-
Cognitive Ability and Behavior in a p-Beauty Contest*

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Abstract

"Beauty contests" are well-studied, dominance-solvable games that generate two interesting results. First, most behavior does not conform to the unique Nash equilibrium. Second, there is considerable unexplained heterogeneity in behavior. In this work, we evaluate the relationship between beauty contest behavior and cognitive ability. We find that subjects with high cognitive ability exhibit behavior that is closer to the Nash equilibrium. We examine this finding through the prism of economic and biological theory.

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I INTRODUCTION

Economics uses mathematical models to predict human behavior. The level of analytic sophistication in these models appears to exceed that of the conscious mental processes being modeled. Is it reasonable to predict human behavior using models that require analysis beyond the ability of all but a few people?

Yes, is the conventional response; complex mathematics underlie human economic behavior, but people need not do any conscious calculations to reach equilibrium. In a famous analogy, Friedman and Savage asked their readers to consider the problem facing an expert billiard player: "the billiard player made his shots as if he knew the formulas... [and] could make the lightning calculations from the formulas." (Friedman and Savage 1948, p 298). Economic behavior, in this view, is produced by an optimizing process of potentially great complexity that need not be directly accessible to the actors.

Economic models commonly omit two nuances contained in Freidman and Savage's original work. First, Friedman and Savage's billiards player is explicitly listed as an expert, which implies a role for learning and suggests that the "as if" does not apply to all people. Second, Friedman and Savage, and later Friedman (1953), use examples where it could plausibly argued that selective forces, such as markets, support an outcome in which economic behavior is reasonably approximated by a rationality assumption. If selection is central to optimal behavior then application of the "as if" should be conditioned upon the selective pressures that are relevant to a particular context. In practice, many economic models eschew such nuances, and utilize a "naïve as if" that assumes all people effortlessly calculate the optimal course of action, and follow that course.

The "behavioral school" has mounted a critique of the naïve "as if" assumption, supported by divergences between behavior predicted by standard economic theory and actual human behavior as observed inside and outside laboratories (Kahneman and Tversky 1979; Kahneman and Tversky 1984; Thaler 1992). The term "anomaly" is used to describe human behavior that is "difficult to reconcile ... within the [standard economic] paradigm" (Dawes and Thaler 1988, p 187).

One well-documented behavioral anomaly is the observation that almost no people act as predicted by standard economic theory in a simple strategic situation called a "beauty contest" (Nagel 1995). In the beauty contest, people compete by simultaneously choosing a number from some finite range, commonly 0 to 100. The winner is the person whose selection is closest to some fraction, p, of the average of all the choices. Ties are either resolved randomly or by dividing the prize equally among the winners. In a commonly studied variant of a beauty contest, p is strictly greater than 0 and strictly less than 1, which implies a unique Nash equilibrium where all choices are identically zero.

In economic models, the path to equilibrium is often unspecified. Moulin did the first analysis of the beauty contest to illustrate that Nash equilibrium can sometimes be found by iterated deletion of weakly dominated strategies (Moulin 1986). Consider, for example, the beauty contest with a range of 0 to 100, and with the parameter, p, set to 0.5. A choice of 50 weakly dominates any selection higher than 50, thus if people eliminate weakly dominated strategies, the interval of choice becomes [0, 50]. However, if all people remove choices above 50, and anticipate others will also, the same logic reduces the range to [0, 25]. In general, after n levels of iteration, the interval shrinks to $[0, 100\mathrm{p}^n]$, which for $0 < \mathrm{p} < 1$ converges to the single point 0. It can be shown that this Nash equilibrium is unique.

Therefore, if all people in a beauty contest behaved as predicted by economic theory, then each would choose 0. The first beauty contest experiment documented large and persistent deviations from this prediction (Nagel 1995). Further research has confirmed this finding while studying the effects of varying stakes, learning, and subject pools (Camerer 2003; Chou et al. 2007; Duffy and Nagel 1997; Ho, Camerer and Wiegelt 1998). Repetition tends to produce convergence toward the Nash equilibrium, in some studies larger stakes are associated with behavior that is closer to equilibrium, and substantial deviations from Nash equilibrium have been documented in a variety of different subject pools. Finally, experimental subjects typically engage in fewer than 3 rounds of iterated dominance (as inferred from their choices).

A series of experiments have sought to expand the scale and scope of the subject pool by running "field" beauty contests in the popular media (Bosch-Domènech and Nagel 1997a, 1997b; Selten and Nagel,1997, 1998; Thaler 1997a,1997b). These experiments had thousands of participants and drew from a much broader (albeit uncontrolled) range of subjects. These large-scale field studies confirmed the earlier work in reporting heterogeneous behavior, and almost no subjects who conformed to the Nash equilibrium (Bosch-Domènech et al. 2002).

In summary, the beauty contest is a relatively simple strategic situation, with a unique Nash equilibrium that is exhibited by almost no one in a wide range of laboratory and field settings. It has been suggested that the failure of Nash equilibrium, the core solution concept in economics, to predict behavior in this simple strategic setting might have broad ramifications. Why do people fail to conform to Nash equilibrium in the beauty contest and what are the implications?

One explanation may be found in the computational complexity of finding equilibrium. If some individuals have difficulty performing the "lightening calculations" of Friedman and Savage, at least in a certain class of problems, this may account for the failure of the Nash equilibrium to be observed in this simple experiment. The original beauty contest paper pursued one such cognitive explanation; Nagel introduced a framework she labeled "depth of reasoning", based conceptually in the notion of bounded rationality (Nagel 1995; Simon 1955). In this framework, people vary in the order of their beliefs about others' beliefs. In each case, level k+1 behavior is a best response to a world filled only with level-k people. Nagel's framework has been formalized and refined in a variety of papers, both in so-called level-k models (Costa-Gomes and Crawford 2006; Stahl 1996, 1998), as well as related cognitive hierarchy models (Camerer, Ho and Chong 2004).

This depth of reasoning view suggests that beauty contest participants may be acting rationally, given their beliefs about the distribution of people who engage in k steps of thinking, but their beliefs about the distribution may be biased. Beauty contest behavior provides some support for this characterization. For example, the modal choices for several of the large field experiments with p = 2/3 were 33 and 22 (Bosch-Domènech et al. 2002). 33 is the level-1 choice, defined as a best response to a world filled with level-0 people who choose randomly within [0, 100]. Similarly, 22 is the level-2 choice that would win in a world full of level 1 people, each selecting 33.

The deviation between human behavior and that predicted by the core equilibrium concept suggests a refinement of the theory. Two sorts of modifications seem plausible. First, the ability to implicitly and non-consciously calculate optimal behavior might vary with problem type and framing. In the discussion section we invoke the natural sciences literature to suggest that the rationality assumption might be expected to work well, even for computationally intensive tasks if the setting lines up appropriately with naturally-selected decision mechanisms (Cosmides and Tooby 1994; Mayr 1961; Tinbergen 1963, 1968). Cognitive ability might play a central role in certain types of economic decisions, and thus explain heterogeneous, non-equilibrium behavior.

There is a nascent literature on cognitive ability and economic behavior. Small-stakes loss aversion and impatience are associated with lower cognitive ability in a series of related studies (Benjamin and Brown 2006; Dohmen et al. 2007; Frederick, 2005). Studies of simple bargaining games report inconsistent relationships between behavior and cognitive ability (Brandstatter and Guth 2002; Millet and Dewitte 2006). In repeated prisoner's dilemmas, a meta-study reports higher levels of cooperation conducted at universities that admit students with higher standardized test scores (Jones 2006). Finally, one recent study examined the relationship between various measures of cognition and dominance violations (Rydval et al. 2007). The authors found that reasoning errors were associated with lower performance on a test of working memory.

However, attempts to study the causal role of cognitive ability can be difficult to differentiate from preference-based explanations. For example, small-scale loss aversion, high discount rates, and cooperation could be produced by perfect 'as if' optimization of loss-averse, impatient, and other-regarding preferences (Bolton 1991; Fehr et al. 2002; Fehr and Schmid, 1999; Gintis 2000; Rabin, 1993), although it is argued that some of these results require implausible preferences (Rabin 2000).

Another clue to the role of cognitive ability comes from "cognitive load" experiments that ask subjects to engage in multiple tasks simultaneously. In one study, higher cognitive loads are associated with higher levels of small stakes loss aversion and lower levels of patience (Benjamin and Brown 2006). In a study of forecasting ability, high cognitive load degrades performance, but this effect can be reversed by higher financial incentives (Rydval 2007). More generally, it has been argued that "rewards reduce the variance of the data around the predicted outcomes." (Smith and Walker 1993, p. 245), a finding consistent with a related meta-study (Camerer and Hogarth 1999).

Further evidence on the role of cognitive ability comes from the centipede game, which has a unique sub-game perfect equilibrium that is observed with a frequency under 10% in student populations (Binmore 1987; McKelvey and Palfrey 1992). Highlighting the role of cognitive ability, one study used high-caliber chess players as subjects in the centipede game. Among these subjects, 69% stopped at the unique sub-game perfect equilibrium of the first node; among the ranked, grand masters 100% of subjects stopped at the first node (Palacios-Huertay and Volijz 2006). Choosing the sub-game perfect equilibrium in the centipede game requires backward induction and the common knowledge of rationality (Aumann and Brandenburger 1995).

The centipede game results highlight the impact of different subject pools on behavior. Interestingly, the vast majority of the existing work on cognitive ability and economic behavior uses university students as subjects. Because the admissions process uses direct and indirect measures of cognitive ability these subjects are not representative of the population.

Any study involving cognitive ability involves two controversies. First, there is considerable debate of the ability to summarize cognitive ability by a single, general factor, sometimes called "g" (Spearman 1904). The concept of g is supported by some and critiqued by others (Plomin and Spinath 2002; Toga and Thompson, 2005). Second, there is evidence that cognitive ability is heritable (Neisser et al. 1996), but there is debate about the extent to which it is malleable with respect to environmental intervention (Heckman 1995).

In spite of these unresolved issues, we favor continued research because cognitive ability scores have high predictive validity for behaviors that are central to economics. These include high correlations between cognitive ability and wages, education, employment, and occupation (Cawley, Heckman and Vytlacil 2001), as well as smoking, illegal drug use, and teen pregnancies (Heckman, Stixrud and Urzua 2006). Furthermore, a study of large stakes retirement decisions finds that lower cognitive ability is correlated with a preference for lump-sum payments over annuities at discount rates of up to 30% (Warner and Pleeter 2001). These relationships are not particularly surprising given that the tests were designed to predict real world outcomes (Geary 2005).

We contribute to the investigation of cognitive ability and economic behavior with an experimental study that has the following attributes. First, we directly test cognitive ability, which we prefer to the use of proxies such as SAT-scores or GPA. Second, we examine behavior in the beauty contest, a setting without any obvious preference-based explanation for non-equilibrium behavior, and where the existing literature suggests a role for cognitive ability via the depth of reasoning analysis. Third, we draw our subject pool from a Swedish population-based registry, which is an improvement over a subject pool of students in terms of representativity.

In sharp contrast to the standard economic view that constraints on computational ability are non-binding, we believe that some economic problems, including the beauty contest, require mobilization of costly cognitive resources. In particular, measurable differences in cognitive ability may in fact underlie differences in the strategic sophistication - for instance an individual's λ parameter in a cognitive hierarchy model, or her type in a level k model - subjects exhibit in economic games. Accordingly, we predict that lower cognitive ability scores will be associated with beauty contest behavior that is farther from Nash equilibrium.

II METHODS

Subjects played a beauty contest with a range of [0, 100] and the parameter p was set at 0.5 (See Appendix A for full beauty contest instructions). The cognitive ability test used is a short, standard psychometric test of general mental ability (Spearman, 1904) developed by the Swedish psychometric company Psykologiförlaget (Sjöberg, Sjöberg and

Forssén 2006). Subjects had twenty minutes to complete the test, and were notified with 5 and 1 minutes remaining. The test is divided into three sections on verbal analogies, logical problems, and mathematical series.

A total of 658 subjects were drawn from a population-based registry in Sweden. Because the subjects were part of a related study on heritability, all were same sex twins. Subjects were born between 1960 and 1985, and were solicited by e-mail and recruited in all major Swedish cities through the summer and fall of 2006. A condition for participation was that both twin siblings be able to participate.

Subjects were, upon arrival, informed about the general proscription against deception in economics. They were further notified that if they felt that there were any ambiguities in the instructions, they should feel free to ask questions, and questions were answered privately. We also stressed, both in the written instructions and orally, that answers would be treated with complete confidentiality. Two subjects did not take the test of general mental ability and these observations were dropped. No subject declined to take part in the beauty contest. In addition, we obtained subjects' age, sex, and level of education.

III RESULTS

As hypothesized, higher cognitive ability scores are correlated with decreased distance from Nash equilibrium in this beauty contest. Visually, this is shown in Figure I where we plot average beauty contest choice, and 95% confidence bands, stratified for each decile in the cognitive ability distribution. Confidence bands are adjusted to take into account covariation between twins. Subjects in the highest two deciles of cognitive ability have an average choice that is very near the revenue maximizing number, whereas subjects in the lowest three deciles have average choices just below 50 (consistent with picking randomly within the feasible set).

Multivariate analysis confirms the relationship between cognitive ability and beauty contest behavior (see Table I). Regressing the distance from Nash equilibrium on cognitive ability and controls which include sex, education and age, the coefficient on cognitive ability is statistically significant ($p<0.0001$). To account for the sample being twins, standard errors are clustered using the general estimating equation framework of Liang and Zeger (1986). Depending on which controls are included, moving up one standard deviation in the distribution of cognitive ability is associated with a 7-10 point decrease in beauty contest choice. We have also evaluated the same specifications with the score of cognitive ability decomposed into the three test subcomponents of numerical, analytical and logical reasoning, and each of the individual scores are significantly correlated with behavior. These results are reported in Table II.

The relationship between cognitive ability and beauty contest is robust as it remains highly significant in all specifications. Beauty contest choice shows a statistically significant increase along with subject age. There is no statistically significant relationship between sex and beauty contest choice. Education, defined as having some college education, is significantly correlated with choices that are closer to Nash. In column 6, we report the results from a regression with dummy variables for all seven educational categories. The dummy variables are not jointly significant ($p=0.15$).

Our results are consistent with the cognitive hierarchy models and with Nagel's depth of reasoning explanation for beauty contest behavior (Camerer, Ho and Chong 2004; Nagel 1995). To explore this we divide beauty contest choices into four categories with break points at $100p^n$, for $n = 1, 2,$ and 3 (see Figure II). Among subjects in the lowest quartile of cognitive ability, just under half chose numbers over 50, while under 10% make choices below 12.5. This behavior is reversed among those in the top quartile of cognitive ability with almost no choices above 50, and more than one-third making choices of under 12.5.

IV DISCUSSION

We find that the 'distance to Nash equilibrium' in a beauty contest is negatively correlated with cognitive ability. This relationship suggests an explicit role for mental ability and effort that is not captured in the traditional economic model of decision making. Our subjects appear to struggle to find the Nash equilibrium, utilize conscious cognitive abilities, and are heterogeneous. As in previous studies of the beauty contest, very few people in our sample conform to the Nash prediction, and choices range from the equilibrium of 0 all the way to the maximum allowed choice of 100. The mean choice in our study is 34.12, versus the unique Nash equilibrium of 0, and the winning choice of 17.06.

The results are consistent with our hypothesis that finding Nash equilibrium in the beauty contest requires the mobilization of scarce and costly cognitive resources. The deviations from Nash equilibrium are strongly negatively associated with cognitive ability. As shown in Figure II, the relationship is so direct that people in the bottom quartile of cognitive ability appear to choose randomly, whereas people in the top quartile, on average, make choices that are very close to the winning number of just over 17. A one standard deviation increase in cognitive ability is associated with playing 7-10 points closer to Nash equilibrium. These results are robust to alternate explanations based in education, sex, and age.

Cognitive ability may play two complementary roles in producing lower beauty contest entries. First, an individual's ability to calculate equilibrium may be a function of cognitive resources. Second, cognitive ability may be associated with a better ability to form accurate beliefs about others. Indeed, a striking feature of the data is that subjects in the top decile provide, on average, a number very near the revenue maximizing choice. On average, these people behave as if they correctly predict the bias of others. If this finding generalized then in mixed populations of rational and 'behavioral' agents, one can imagine the endogenous evolution of institutions which permit rational types to systematically exploit the biases of the more behavioral types (Glaeser, 2004; Levitt and List, 2007). For example, there is evidence that sports clubs design contract options to profit from consumer irrationality (DellaVigna and Malmendier 2006).

Our results are in general agreement with non-beauty contest studies reporting that behavioral anomalies are more common among subjects with low cognitive ability scores (Benjamin and Brown 2006; Dohmen et al. 2007; Frederick 2005). Furthermore, we believe that these experimental settings are cognitively simple as compared to many important economic decisions that people must make. If people have trouble finding Nash equilibrium in an experimental beauty contest, one ought not be too surprised if some people have difficulty navigating financial markets or making good career or mate choice decisions.

Clearly, human behavior in the beauty contest is inconsistent with any purist assumption that all individuals behave "as if" rationally. In this particular situation, such an assumption is not a useful abstraction and obscures an important source of behavioral heterogeneity. The robust correlation between cognitive ability and behavior in the beauty complements theoretical work aimed at explaining the failure to observe Nash equilibrium (e.g. Camerer, Ho and Chong 2004). In such models, there is a distribution of the number steps of iterated strategic reasoning players are capable of engaging in. Our results suggest that individual differences in cognitive ability can explain why some individuals are more strategically sophisticated than others. Cognitive limitations are, we believe, a major contributing factor to the failure to observe equilibrium. When the "as if" fails to make accurate predictions, we agree with Herbert Simon in favoring economic models that assume people have such cognitive limitations (Simon 1955).

The economic significance of behavioral anomalies observed in the laboratory is under active debate. For example, Ken Binmore argues against taking experimental evidence uncritically, suggesting that people get to equilibrium "by an interactive process of trial-and-error learning" (Binmore 1999). This experiential process may be quite different from standard views of rationality, but in repeated settings may converge to the standard behavior. In fact, with experience, beauty contest behavior generally converges toward the equilibrium.

Beyond experience, a form of selection may also limit the economic costs of behavioral anomalies. A series of papers concludes that people who are in a market frequently tend to behave as predicted by standard economic theory (List 2003). As noted by Gary Becker, persistent failures in the laboratory to make, for example, accurate probability judgments only matter if people in the field make the same mistakes (Clement 2002). For instance, it is possible that people who self-select into professions where calculating probabilities is important (e.g., professional traders) might be above average in the abilities that are relevant. Thus, a variety of institutional factors may serve to mitigate the extent to which behavioral anomalies persist in the real world (Levitt and List, 2007).

Others argue, however, that behavioral anomalies can persist despite ample scope for learning (Alevy, Haigh and List 2007; Mullainathan and Thaler 2001), and in some settings irrationality at the individual level can be magnified, not mitigated, at the group level (Fehr and Tyran 2005). Finally, Richard Thaler has critiqued the view that learning and selection minimize the relevance of behavior anomalies, noting that some of the most important decisions such as career choice, marriage partner, and number of children do not easily allow for trial-and-error learning or selection (Thaler 2000).

Returning to the high-level question of the human brain and the billiards player, one might ask why people should be expected to be rational decision-makers. An obvious answer is that evolution by natural selection should favor good problem solvers over bad. Furthermore, if natural selection is the shaping force for producing good decision making machinery, there is no reason to limit the outcome to conscious cognition.

Myriad animal studies provide support for the idea that natural selection does favor, and produce, organisms with remarkably sophisticated behaviors. For example, dungflies, Scatophaga sterocoraria, exhibit Nash equilibrium behavior when they compete for resources in a war of attrition (Hendricks and Wilson 1988; Maynard Smith and Price 1973; Parker 1970). The field of behavioral ecology is filled with thousands of specific demonstrations that animals exhibit behavior that is completely consistent with the "as if" assumption of economics (Daly and Wilson 1983; Krebs and Davies 1996).

How does one reconcile smart flies and silly people? If natural selection favors optimizing behavior, and organisms with tiny brains perform the lightening calculations, why do we find in this beauty contest study that only the people with highest cognitive ability behave optimally? Put differently, there is a sense in which our proposed explanation of the puzzling failure to arrive costlessly to the Nash equilibrium merely solves one puzzle by creating another one. The computational complexity of finding the Nash equilibrium by iterated dominance is utterly trivial compared to some of the much more computationally challenging tasks of which humans seem capable. For example, humans are endowed with face recognition capacities that exceed that outperform most computers, and humans also have very effective cheater detection mechanisms (Cosmides and Tooby 1992). This interpretation is consistent with recent evidence that dominance violations are much rarer when games are framed in a manner that is designed to be more 'natural' (Chou et al. 2007).

These results are consistent with understanding that natural selection works on the decision making machinery, not directly on behavior. This distinction between the underlying selective pressure for optimal behavior and the specific mechanisms that produce behavior became a central aspect of ethology in the second half of the 20th century (Mayr 1961; Tinbergen 1963, 1968). The distinction between the force of natural selection, and its reification in bodies and brains, is that the sophisticated machinery that evolved to optimize can produce behavior that seems irrational or, at the other extreme, behavior that is 'better than rational' (Cosmides and Tooby 1994). This view suggests that animals, including humans, can look silly or smart depending on the relationship between the current context and the environment that shaped the relevant mental machinery (Bowlby 1969; Irons 1998).

Cognitive overrides may be utilized when more automatic decision-making machinery favors costly behavior. Accordingly, we hypothesize that the need for conscious, cognitive involvement rises along with divergence between modern and ancestral problems. Just as dungflies are naturally good at solving ancestral problems, the role of cognitive ability in human economic behavior may be less important for ancient problems and greater for evolutionarily novel problems. For example, face recognition is an important part of reputation management, and the modulation of social exchange is a problem that has very deep evolutionary roots (Cosmides and Tooby 1992, Trivers 1971). Accordingly, we hypothesize that social exchange mechanisms such as face recognition or cheater detection will exhibit low correlation with cognitive ability.

In summary, we believe the billiard player's "as if" is a useful abstraction for the function of the human brain in some situations. We are intrigued by the possibility of creating a framework for the likely usefulness of this simplified approach.

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VI Tables and Figures

	Table I. Dependent Variable: Beauty Contest Choice					
	(1)	(2)	(3)	(4)	(5)	(6)
Cognitive Ability	-9.67**	-8.66**	-9.47**	-8.81**	-7.61**	-7.57**
	(0.92)	(0.95)	(0.96)	(1.01)	(1.04)	(1.07)
Age (in yrs)	-	0.50**	-	-	0.48**	0.50**
	-	(0.13)	-	-	(0.13)	(0.14)
1 if female	-	-	2.53	-	2.46	1.96
	-	-	(2.24)	-	(2.28)	(2.26)
1 if college educated	-	-	-	-4.68*	-4.88*	-
	-	-	-	(2.17)	(2.17)	-
Educ Dummies?	NO	NO	NO	NO	NO	YES
Constant	34.04**	17.66**	32.03**	37.22**	19.84**	-
	(0.95)	(4.15)	(1.96)	(1.82)	(4.68)	-
Observations	656	656	656	656	642	642
R^2	0.165	0.187	0.166	0.171	0.195	0.202

Heteroskedasticity robust standard errors in parentheses., clustered at the family level.

* significant at 5%; ** significant at 1%.

	Table II. Dependent Variable: Beauty Contest Choice					
	(1)	(2)	(3)	(4)	(5)	(6)
Numerical	-3.41**	-2.80**	-3.29**	-3.11**	-2.41**	-2.44**
	(0.92)	(0.95)	(0.96)	(1.01)	(1.04)	(1.07)
Analytical	-5.94**	-5.35**	-5.80**	-5.44**	-4.74**	-4.58**
	(1.13)	(1.13)	(1.14)	(1.13)	(1.13)	(1.15)
Logical	-3.10**	-3.02**	-3.16**	-2.84**	-2.88**	-2.81**
	(1.01)	(1.00)	(1.01)	(1.05)	(1.05)	(1.04)
Age (in yrs)	-	0.48**	-	-	0.47**	0.48**
	-	(0.13)	-	-	(0.13)	(0.14)
1 if female	-	-	1.80	-	1.62	1.47
	-	-	(2.23)	-	(2.28)	(2.25)
1 if college educated	-	-	-	-4.45*	-4.30*	-
	-	-	-	(2.15)	(2.16)	-
Educ Dummies?	NO	NO	NO	NO	NO	YES
Constant	34.05**	18.34**	32.62**	37.05**	20.36**	-
	(0.94)	(4.23)	(1.97)	(1.78)	(4.84)	-
Observations	656	656	656	656	642	642
R^2	0.170	0.191	0.171	0.175	0.196	0.204

Heteroskedasticity robust standard errors in parentheses., clustered at the family level.

* significant at 5%; ** significant at 1%.

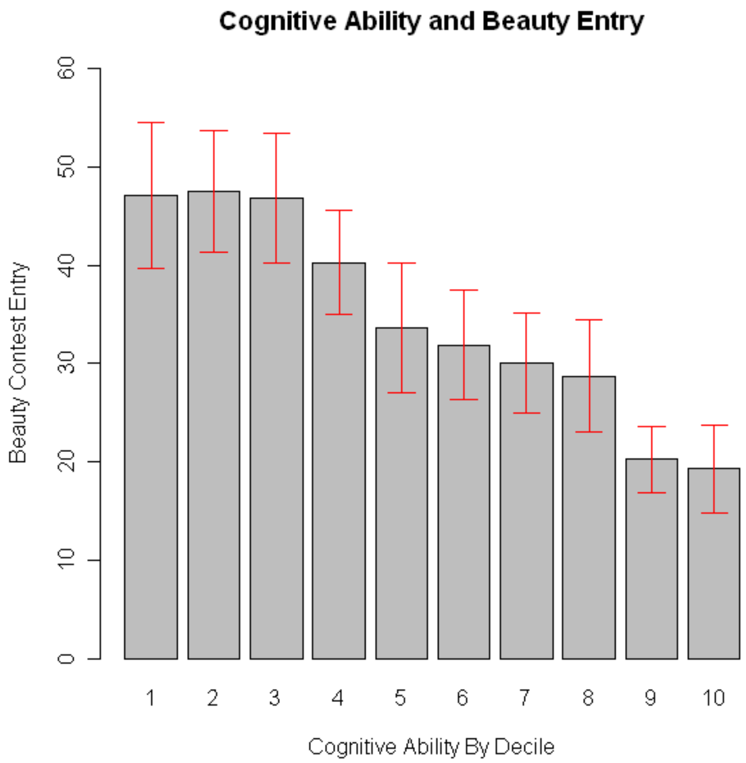

Figure I. Beauty Contest Entry and cognitive ability (by decile), 95 % standard error bars are shown.

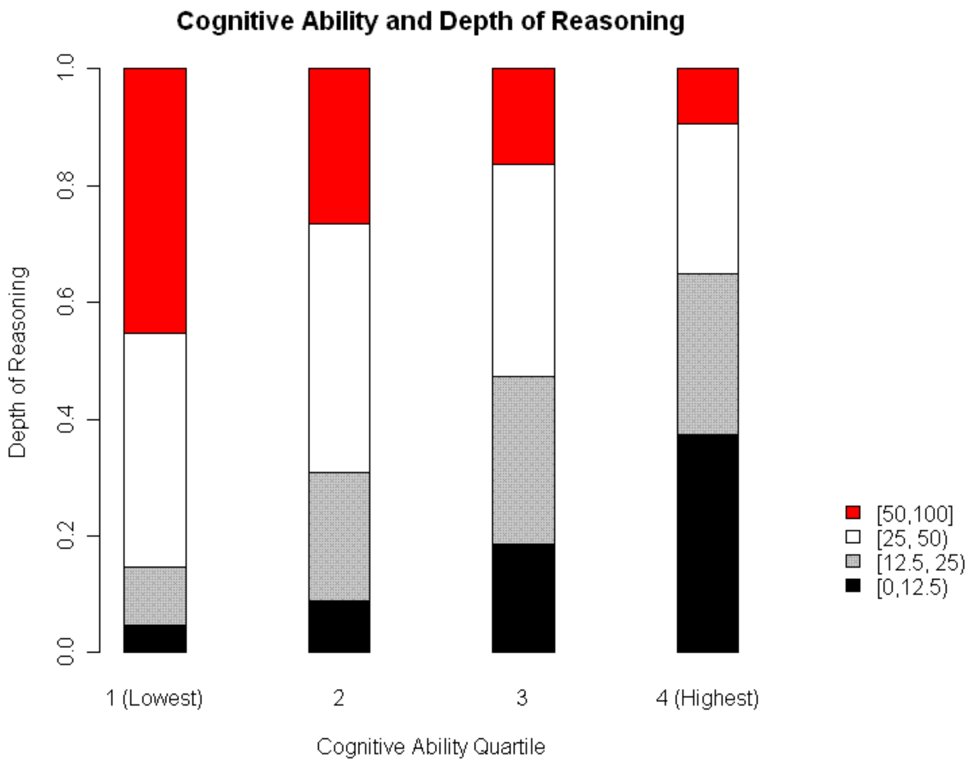

Figure II. "Depth of reasoning" and cognitive ability. We divide beauty contest choices into four categories with break points at 100p^n, for n = 1, 2, and 3.

VII Appendix A– Instructions (translated from Swedish)

"In this section you will take part in a guessing contest. Your task is to guess a number between 0 and 100. All participants of this study will be asked to provide a guess (several hundred people take part in the study). The person whose guess is closest to half the average guess will win 1000 SEK (for instance, if the average guess is 50, the person whose guess is closest to 25 will win the 1000 SEK). Please indicate your guess below."